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ROSAT OBSERVATIONS OF THE COMPOSITE SUPERNOVA REMNANT G326.3−1.8

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ABSTRACT

We have observed X-ray emission from the radio-defined composite (shell plus filled-center plerion) Galactic supernova remnant (SNR) G326.3−1.8 with the *ROSAT* position sensitive proportional counter (PSPC). The data are best fitted by a single-component, thermal line spectrum with temperature $kT = 0.56 \pm 0.04$ keV, hydrogen column density $N_{\rm H} = 8.9 \pm 0.3 \times 10^{21}$ cm^{-2}, and unabsorbed X-ray flux $F_{x0} = 3.9 \pm 0.5 \times 10^{-10}$ ergs cm^{-2} s^{-1} (0.1–2.4 keV). The standard Sedov analysis with an assumed initial kinetic energy $\epsilon_0 = 10^{51}$ ergs gives a radius $R \simeq 20$ pc, distance $D \simeq 3.7$ kpc, age $t \simeq 1.0 \times 10^4$ yr, X-ray luminosity $L_x \simeq 6.1 \times 10^{35}$ ergs s^{-1} (0.1–2.4 keV), and an ambient interstellar medium (ISM) density $n_0 \simeq 0.1$ cm^{-3}.

The derived distance falls within the range of a variety of previous but poor and uncertain distance estimates and is consistent with the only reliable lower limit of $D \geq 1.5$ kpc. Evidence exists in the literature from both optical and radio studies that would place the SNR significantly further than this lower limit. Higher quality radio H I absorption measurements are warranted to confirm our distance determination. Since D scales only weakly with ϵ_0 ($D \propto \epsilon_0^{2/5}$), this result, along with other recent *ROSAT* studies of SNRs, implies that improved distance estimates may be established for the large number of extended shell-type SNRs with very poor distance estimates which fall within *ROSAT*'s all-sky survey.

No X-ray analog to the plerionic radio emission appears on our *ROSAT* image, but our exposure is not sufficient to establish a stringent limit on any filled-center nonthermal X-ray emission. An indistinguishable nonthermal component with spectral index $-0.5 \leq \alpha \leq -4$ ($S \propto \nu^{+\alpha}$) could be present with a luminosity comparable to or exceeding that of the detected thermal component, particularly in light of the significant absorption that our results indicate must exist toward this distant source. A deeper X-ray exposure is required to set more meaningful limits on any plerionic X-ray emission.

Subject headings: ISM: individual (SNR G326.3−1.8) — supernova remnants — X-rays: interstellar

1. INTRODUCTION

It has long been realized that X-ray observations of Galactic supernova remnants (SNRs) offer an excellent complement to existing radio and optical studies and can significantly impact determining their classification and derived physical properties (Heiles 1964; Winkler & Clark 1974). While previous X-ray measurements have typically been follow-ups to existing radio studies, the *ROSAT* all-sky survey has led to the discovery of at least two new SNRs (Pfeffermann, Aschenbach, & Predhl 1991; Greiner & Egger 1993), and the well-known incompleteness in existing radio-based SNR catalogs (Green 1984, 1988a, b) implies that discoveries of more SNRs through their X-ray emission will follow. Recent observations of known SNRs with *ROSAT* have proven fruitful (e.g., Aschenbach et al. 1991; Guo & Burrows 1992), and demonstrate a significant improvement over earlier observations because of *ROSAT*'s sensitivity and spectral and angular resolution.

X-ray observations are particularly suited for distinguishing between plerionic (filled-center) and shell-type SNRs and therefore can be extremely useful for delineating the properties of the complex, and now well-established, class of composite SNRs which display both plerionic and shell-like properties. A few years ago, Weiler & Sramek(1988) reviewed the status of the traditional division of SNRs into shell-type and plerionic/composite and compiled a list of the known or suspected members of the latter class. At that time they showed over 20 possible members of the plerionic/composite class which, when adding the possibly related class of "centrally influenced" SNRs, constituted a significant fraction of the total number (~ 150) of then known remnants. Thus, in spite of arguments over the years that plerionic/composite SNRs are infrequent and few, the actual numbers are relatively large. However, many of the proposed plerionic/composite SNR candidates require confirmation before their statistics and their influence on Galactic evolution can be reliably estimated. This is because of uncertainties related to classifications based on radio emission alone (e.g., at radio wavelengths plerions can easily be confused with H II regions which can have similar flat continuum spectra and filled-center morphology). The best way to provide such confirmation is through X-ray observations. The central neutron star necessary to establish and maintain a plerion usually produces a small, nonthermal X-ray nebula near the center of the radio emission, often with an even more compact core of X-ray emission. This nonthermal plerionic X-ray emission is usually distinguished by its spectrum from the thermal X-ray emission expected from a shell-like com-

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ponent. See, for example, Seward (1983, 1988, 1989), Reynolds & Chanan (1984), and Wilson (1986) for discussions of X-ray observations of plerionic/composite SNRs.

In this paper we present *ROSAT* PSPC observations of the composite SNR G326.3 − 1.8. This SNR displays the classic composite radio signature of a flat-spectrum plerionic component embedded within a steeper spectrum radio shell. In § 2 we review previous results related to this source, and in §§ 3 and 4 we present the results of our new X-ray observations. In §§ 5 and 6 we conduct the standard Sedov analysis and discuss this in the context of previous studies of the source. Our conclusions and thoughts regarding useful follow-up studies are presented in § 7.

2. PREVIOUS STUDIES OF G326.3 − 1.8

G326.3 − 1.8 (also known as MSH 15–56) is well known as a classic example of a composite SNR. It has been extensively studied in the radio regime (see Milne et al. 1989, and references therein) where it exhibits a relatively steep spectrum ($\alpha \simeq -0.4$, with $S \propto \nu^{+\alpha}$) radio shell approximately 36′ in diameter surrounding a flat spectrum ($\alpha \simeq -0.1$) plerionic component approximately 10′ in diameter. The inner component exhibits significant linear polarization as is typical for plerions (Whiteoak & Gardner 1971; Milne 1972; Milne et al. 1989; Weiler & Sramek 1988).

The distance estimates to this SNR based on H I absorption measurements have been reviewed by Green (1984) and are uncertain and contradictory. Caswell et al. (1975) place a firm lower limit on the distance of ≥1.5 kpc, but estimates of 4 ± 2 kpc (Ilovaisky & Lequeux 1972a, b) and greater than 6.5 kpc (McGee, Gardner, & Robinson 1967) among others argue for a much larger distance. Weiler & Panagia (1980), in their study of plerion evolution, prefer a distance of ≃4.6 kpc. We have examined the H I absorption spectrum from Goss et al. (1972), which appears to be of fair quality. It certainly confirms the lower limit of ≥1.5 kpc. Furthermore, if we take the last "real" absorption at $\simeq -40$ km s^{-1}, as seems reasonable, we obtain (bimodal) kinematic distance lower limits of ≥3 kpc and ≥13 kpc based on the Schmidt (1965) model of Galactic rotation. Clearly the distance is very poorly known, and much better H I observations are warranted to improve the determination. We therefore accept only a firm lower limit of ≥1.5 kpc, with an understanding that the source may be much more distant. There is little point in using the surface brightness-distance (Σ–D) relation as discussed by Clark & Caswell (1976) to obtain a distance estimate, as there is now general agreement in the community (see, e.g., Green 1984) that the relationship is highly unreliable.

The H I absorption profile of Goss et al. (1972) also allows us to estimate a lower limit of $N_H \geq 1.7 \times 10^{21}$ cm^{-2} to the integrated H I column density. Optical observations (Dennefeld 1980) indicate a visual extinction A_v of at least 5.1 mag. If one uses an empirically determined linear relationship which roughly relates visual extinction and H I column density ($N_H \simeq 2.2 \times 10^{21} A_v$; Gorenstein 1975), this optical measurement predicts $N_H \geq 1.1 \times 10^{22}$ cm^{-2}. Van den Bergh (1979) has detected Hα emission from the shell, but was unable to detect optical emission from the plerionic component. It may be significant that when Dennefeld (1980) adopts Clark & Caswell's (1976) distance estimate of 3.2 kpc based on the highly unreliable Σ–*D* relationship, only a significantly higher than average local absorption can reconcile his measured A_v with Lucke's (1978) estimate that the average extinction within 2 kpc of the Sun in that direction is only about 1 mag. Together with van den Bergh's (1979) conclusion that the object lies in a highly reddened field, these optical observations are compatible with the source being significantly farther away than 1.5 kpc.

Previous X-ray observations of G326.3 − 1.8 by the *Einstein Observatory* have been presented by Seward (1989, 1990); these are discussed in the context of our new *ROSAT* X-ray results in § 4 below.

3. NEW *ROSAT* X-RAY OBSERVATIONS

Observations of the Galactic SNR G326.3 − 1.8 were obtained using the PSPC (Position Sensitive Proportional Counter) detector aboard the *ROSAT* X-ray Observatory 1991 March 14–15. The data were obtained in three exposures providing a total integration time of 3975 s. The PSPC counts photons and generates pulses which are tagged based on their position, energy, and time of arrival within the detector. The satellite's attitude measurement and control system is then used to determine the pointing of the instrument at the time of each event in order to project the measurements on to the usual frame of sky coordinates (Pfeffermann et al. 1991). The intrinsic field of view is approximately 2°. A complete description of the satellite and its instruments is given by Trümper (1983).

The energy range of the telescope is 0.1–2.4 keV, and the effective collecting area is about 220 cm^2 at 1 keV on-axis and decreases slightly with increasing field angle. The angular resolution is limited by the PSPC to about 25″ on-axis and increases to a few arcminutes for field angles larger than about 20′. The energy resolution is $\Delta E/E = 0.41(E/1\ \text{keV})^{-1/2}$. A detailed description of the mirror assembly and the PSPC can be found in the papers of Aschenbach (1988), Beckstette, Aschenbach, & Schmidt (1988), and Pfeffermann et al. (1986).

4. RESULTS

A contour map of our PSPC image of the field containing G326.3 − 1.8 is shown in Figure 1. It reveals a region of extended soft X-ray emission coincident with the location of the SNR as deduced from radio observations (see Milne et al. 1989). This can be seen in Figure 2 where the 843 MHz radio contours from Milne et al. are superposed over the *ROSAT* X-ray contours. The *ROSAT* X-ray image also corresponds closely to the harder (∼0.2–4 keV) X-ray image of G326.3 − 1.8 as observed by *Einstein* (Fig. 3, Seward 1990).

The total number of counts detected by the *ROSAT* PSPC, after suitable background subtraction, was ≃9170 in the energy range 0.1–2.4 keV, and corresponds to a raw source count rate of 2.31 counts s^{-1}. For comparison, the count rate in the *Einstein* IPC was 1.10 ± 0.10 counts s^{-1}, which is consistent with the predicted IPC rate based on the estimated ratio of sensitivities between the two instruments and our *ROSAT* derived estimate of the neutral hydrogen column density along the line of sight (see below).

Because of the composite radio morphology, single- and dual-component models having regions corresponding to the shell-like and plerionic radio components (see § 5 and Fig. 2) were fitted by power law, pure thermal, and thermal with line model spectra. The data are best fitted by a single component Raymond-Smith (1977) thermal spectrum with lines ($\chi^2 = 34.6$ for 30 degrees of freedom) and modified by the interstellar photoelectric absorption cross sections given by Morrison & McCammon (1983.) The model spectrum is plotted along with

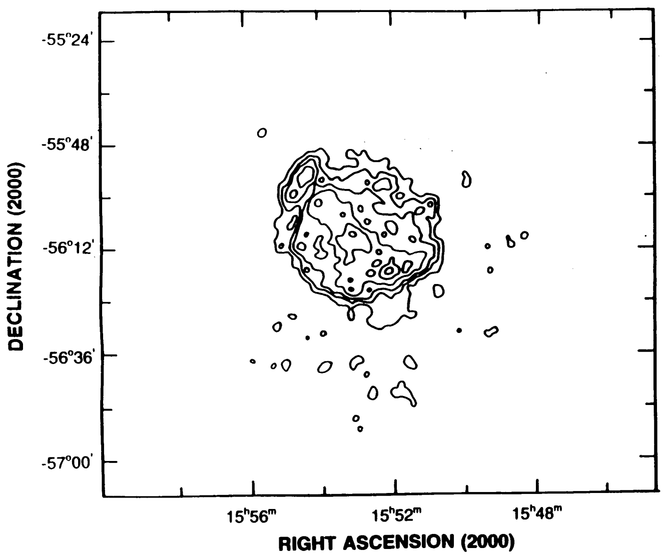

FIG. 1.—*ROSAT* PSPC X-ray image of the Galactic SNR G326.3−1.8. The image has been smoothed with a 45″ Gaussian which approximates the resolution of the X-ray image. Contour levels are at (0.35, 0.50, 0.70, 1.00, 1.40, 1.80) in units of 4×10^{-3} counts s^{-1} arcminute^{-2}.

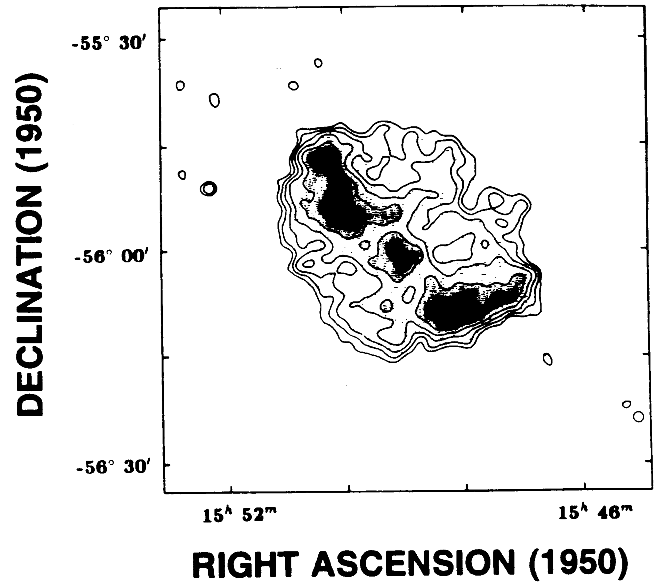

FIG. 3.—*Einstein Observatory* IPC (energy range 0.2–4 keV) X-ray image of G326.3−1.8 reproduced from Seward (1990). The gray scale is approximately linear and is normalized to black at maximum intensity. The contour intervals are a factor of 1.5 in brightness. See Seward (1990) for further details.

the data in the top panel of Figure 4, and the bottom panel displays the residuals. Figure 5 displays the χ^2 contours in the log (N_H)-kT plane. The model fit yields a derived electron temperature of $kT \simeq (0.56 \pm 0.04)$ keV or $T \simeq (6.5 \pm 0.6) \times 10^6$ K, and a derived neutral hydrogen column density of $N_H \simeq (8.9 \pm 0.3) \times 10^{21}$ cm^{-2}. Note that the *ROSAT* derived value of N_H is in reasonably good agreement with the rough independent prediction based only on optical extinction measurements of $\geq 1.1 \times 10^{22}$ cm^{-2}, given the uncertainties of that estimate (see § 2). The observed energy flux of the source within the *ROSAT* energy band (0.1–2.4 keV) is $F_x \simeq (2.6 \pm 0.1) \times 10^{-11}$ ergs cm^{-2} s^{-1} and the inferred unabsorbed flux is $F_{x0} \simeq (3.9 \pm 0.5) \times 10^{-10}$ ergs cm^{-2} s^{-1}.

In the analysis that follows, the X-ray emission from G326.3−1.8 is modeled assuming the SNR is a shell-type SNR in the adiabatic expansion phase. However, we note that, except for the northeast region of the SNR, the morphology of the X-ray emission is not very shell-like. Since a blast wave analysis is more plausible if the remnant looked more shell-like, the strong central emission may suggest a more complicated model requiring evaporative clouds, an inhomogeneous

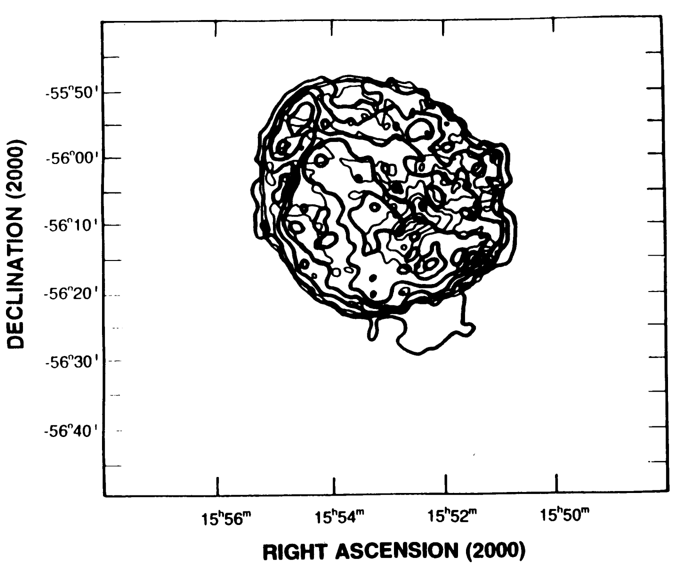

FIG. 2.—*ROSAT* PSPC X-ray image from Fig. 1 (*thick dark lines*) superposed on Milne et al. (1989) 843 MHz radio image (*thin dark lines*). The radio contours are at the 2.5, 5, 10, 25, 50, 75, and 90 percentile levels, with a peak of 326 mJy beam^{-1}. The angular resolution on the radio map is approximately 43″ (E-W) by 52″ (N-S).

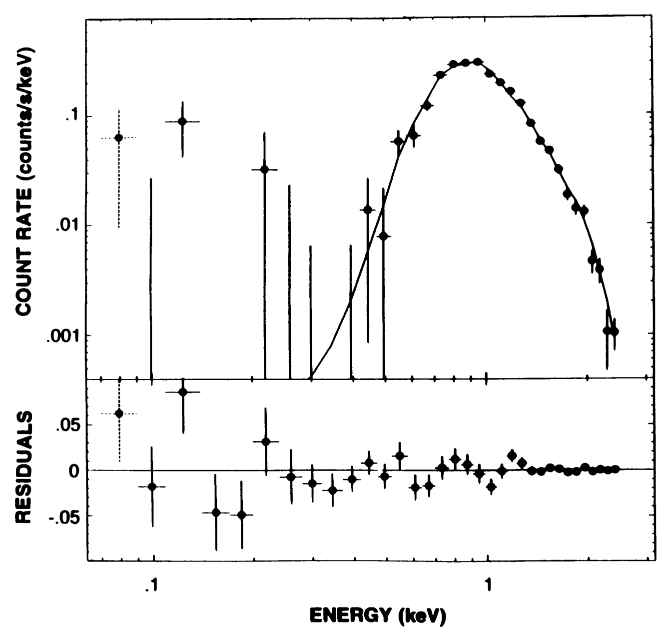

FIG. 4.—*Top panel: ROSAT* PSPC total energy pulse height spectrum (*filled circles*) and best-fitting thermal line spectrum (*solid line*) with $N_H = 8.9 \times 10^{21}$ cm^{-2} and $kT = 0.56$ keV for G326.3−1.8. *Bottom panel:* residuals between the data and best-fitting thermal model. Both plots have units of counts s^{-1} keV^{-1}.

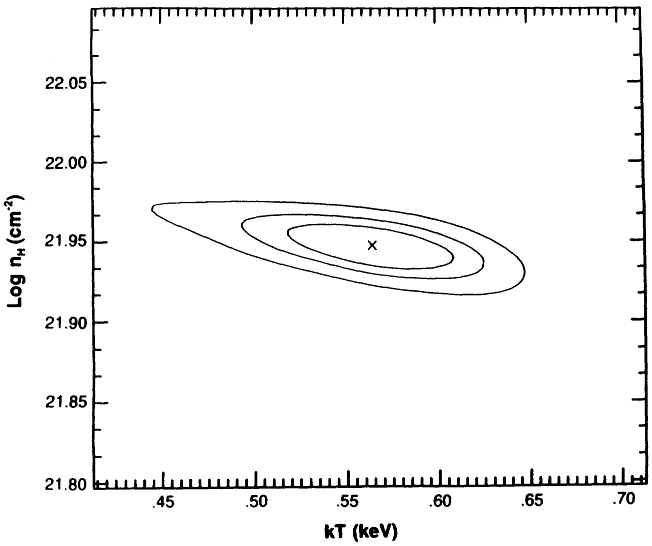

FIG. 5.—Contours of χ^2 in the N_H–kT plane for the thermal spectrum with lines fit shown along with the data in Fig. 4. Contours are at confidence levels of 68% (1 σ), 90%, and 99%. The cross marks the best-fit spectrum shown in Fig. 4.

ISM, or some other unusual geometry. Noting this, we fitted a thermal spectrum to the northeast region alone and derived parameters which are identical, within the statistical errors, to the parameters derived from fitting the X-ray emission from the entire remnant. For the northeast region alone we derived an electron temperature of $kT \simeq (0.59 \pm 0.08)$ keV and a neutral hydrogen column density of $N_H \simeq (8.9 \pm 0.6) \times 10^{21}$ cm^{-2}. The observed energy flux of the northeast region alone, within the *ROSAT* energy band (0.1–2.4 keV), is $F_x \simeq (0.56 \pm 0.01) \times 10^{-11}$ ergs cm^{-2} s^{-1} and the inferred unabsorbed flux is $F_{x0} \simeq (0.81 \pm 0.19) \times 10^{-10}$ ergs cm^{-2} s^{-1}. For comparison the "scaled up" flux from this region, which occupies only ~17% of the total area of X-ray emission, is $F_{x0} \simeq (4.8 \pm 1.1) \times 10^{-10}$ ergs cm^{-2} s^{-1}. This value is slightly higher than, but consistent with, the flux determined from fitting all the X-ray emission. In the remainder of this paper, we adopt the model parameters derived from fitting a single thermal spectrum to the entire region of X-ray emission and summarized in Table 1.

TABLE 1

MEASURED, FITTED, AND DERIVED PROPERTIES OF G326.3−1.8

Property	Value
Measured Properties[a]:	
F_x (ergs s^{-1} cm^{-2})	$(2.6 \pm 0.1) \times 10^{11}$
θ (arcminutes)	38 ± 1
Fitted Properties[b]:	
kT (keV)	0.56 ± 0.4
N_H (cm^{-2})	$(8.9 \pm 0.3) \times 10^{21}$
F_{x0} (ergs s^{-1} cm^{-2})	$(3.9 \pm 0.5) \times 10^{-10}$
Derived Properties[c]:	
D (kpc)	3.7 ± 0.2
R (pc)	20.4 ± 0.9
n_0 (cm^{-3})	0.14 ± 0.01
t_4 (10^4 yr)	1.04 ± 0.09
L_x (ergs s^{-1})	$(6.1 \pm 0.7) \times 10^{35}$
V_s (km s^{-1})	770 ± 35
M_{su} ($M_\odot$)	123 ± 11

[a] See § 4.
[b] See § 4.
[c] See § 5.

5. ANALYSIS

The outer contours of the radio emission from G326.3−1.8 (Fig. 2) define the steeper spectrum radio shell ($\alpha \simeq -0.4$) while the smaller condensation located within the shell and centered near R.A. = 15^{h}52^m.5, decl. = −56°13′ (epoch J2000) corresponds to the flatter spectrum plerionic component ($\alpha \simeq -0.1$). In our PSPC image there appears to be no condensation in the X-ray emission analogous to the radio plerion. A similar result was noted by Seward (1989) in the *Einstein* observation of G326.3−1.8. The close correspondence between the outlines of the radio shell and X-ray emission (Fig. 2) and the success of the single-component thermal spectrum fit for the X-ray emission (Fig. 4) suggest that the shell component of G326.3−1.8 is in the adiabatic expansion phase of its evolution. We therefore apply the standard Sedov (1969) analysis to G326.3−1.8 following the outline of Winkler & Clark (1974).

The Sedov similarity solution for the equation of motion in the adiabatic expansion phase of a shell-type SNR evolution is

$$R \simeq 14\left(\frac{\epsilon_0}{n_0}\right)^{1/5} t_4^{2/5} , \tag{1}$$

where R is the radius of the supernova shock front in pc, ϵ_0 is the initial kinetic energy of the SN explosion in units of 10^{51} ergs, n_0 is the ambient ISM hydrogen density in cm^{-3}, and t_4 is the time since the supernova explosion in units of 10^4 years. The velocity of the shock front V_s in km s^{-1} can be determined by differentiating equation (1),

$$V_s \simeq 39 R t_4^{-1} . \tag{2}$$

If the medium in front of the shock is cold, then the pressure and density of the swept-up material behind the shock will be given by the Rankine-Hugoniot relations for a strong shock. Substituting these into the ideal gas law, and assuming a mean molecular weight of 0.5 behind the shock (Woltjer 1972), gives the shock temperature T in degrees K:

$$T \simeq 11 V_s^2 . \tag{3}$$

The swept-up mass M_{su} in solar masses is simply

$$M_{su} \simeq 0.10 n_0 R^3 . \tag{4}$$

The X-ray luminosity L_x of the SNR in ergs s^{-1} is given by (Winkler & Clark 1974)

$$L_x \simeq 3 \times 10^{56} R^3 n_0^2 P(\Delta E, T) , \tag{5}$$

where $P(\Delta E, T)$ describes the power emitted by hot electrons in a low-density plasma via free-free emission and is a function of energy band and temperature. For the PSPC energy band (0.1–2.4 keV) and our measured temperature for G326.3−1.8 (0.56 keV), $P(\Delta E, T) \simeq 1.3 \times 10^{-23}$ ergs cm^3 s^{-1} (Tucker & Koren 1971).

Finally, from purely geometric considerations, we can relate the observed angular diameter of the X-ray (or radio) shell θ (in arcminutes) to the physical shell radius R (in pc) and the SNR distance D (in kpc)

$$R = 0.15 D\theta , \tag{6}$$

and the X-ray luminosity L_x to D and F_{x0}, the observable X-ray flux density in ergs s^{-1} cm^{-2} after correction for inter-

stellar absorption,

$$L_x = 1.2 \times 10^{44} D^2 F_{x0} . \quad (7)$$

Since the only firm distance estimate for G326.3−1.8 is a lower limit of $D \geq 1.5$ kpc with indications in the literature that the source may be considerably farther (see § 2), we choose to assume the canonical value of $\epsilon_0 = 10^{51}$ ergs for the supernova explosion energy as our primary assumption and derive the distance D from our observations. We measure $\theta = 38 \pm 1$ arcminutes from the X-ray data (the radio map gives a similar value, see Figs. 1 or 2) and we use the *ROSAT* determined temperature and unabsorbed flux density, $T = (6.5 \pm 0.6) \times 10^6$ K and $F_{x0} = (3.9 \pm 0.5) \times 10^{-10}$ ergs s^{-1} cm^{-2}. We can then derive the following parameters for G326.3−1.8: $D = 3.7 \pm 0.2$ kpc, $R = 20.4 \pm 0.9$ pc, $n_0 = 0.14 \pm 0.01$ cm^{-3}, $t_4 = (1.04 \pm 0.09) \times 10^4$ yr, $L_x = (6.1 \pm 0.7) \times 10^{35}$ ergs s^{-1}, $V_s = 770 \pm 35$ km s^{-1}, and $M_{su} = 123 \pm 11\ M_\odot$. The last is greater than any reasonable estimate of the initial ejected mass and serves as a self-consistency check to ensure that the SNR has passed the free-expansion phase and reached the adiabatic phase as assumed. (See Woltjer 1972 for a review of the various phases of SNR expansion.) These measures, fitted, and derived properties are also summarized in Table 1.

Equations (1)–(6) indicate how the various parameters scale with respect to an assumed value of ϵ_0: $n_0 \propto \epsilon_0^{-0.2}$; D, R, and $t_4 \propto \epsilon_0^{0.4}$; $L_x \propto \epsilon_0^{0.8}$; and $M_{su} \propto \epsilon_0^{1.0}$. Thus only L_x and M_{su} are strongly dependent on the assumed value of ϵ_0. A similar assumption of $\epsilon_0 = 10^{51}$ ergs was made by Pfeffermann et al. (1991), who noted that numerical calculations of Type I supernova by Nomoto, Thielemann, & Yokoi (1984) showed little variation of ϵ_0 over the range 0.9–1.5 × 10^{51}. While Type II events may have higher values of ϵ_0, we assume here that they are not likely, at least on average, to be significantly higher. Varying ϵ_0 has little effect on perhaps the most important of our derived parameters, the distance D. The range of (0.9–1.5) × 10^{51} ergs for ϵ_0 leads to a range in D of only 3.5–4.4 kpc, which is small compared to the large uncertainty in the distance estimate obtained from radio measurements and is only slightly larger than the formal errors quoted above based on the uncertainties in our measurements. Note that varying ϵ_0 over the range would not change M_{su} enough to threaten the validity of the adiabatic assumption.

It is important to note that the assumption of ϵ_0 is not made lightly, but is necessary in order to solve a difficult problem where the number of physical parameters exceeds the number of observables. The total energy released in the gravitational collapse of a star during a supernovae is $\sim 10^{53}$ ergs, and thus the assumed kinetic energy ϵ_0 is only ~ 1% of the total. The exact value is probably determined randomly and varies rather than being a constant value for all Type II supernovae. It is not implausible that much larger values of ϵ_0 occur for some Type II events.

6. DISCUSSION

The parameters derived from the Sedov analysis listed in Table 1 appear reasonable and fall within the normal range for other shell-type SNRs. Perhaps the most interesting result is that the distance estimate of 3.7 kpc is significantly higher than the only reliable lower limit of 1.5 kpc. However, as discussed in § 2, it is consistent with evidence from both optical and radio studies that would place the SNR significantly further than this. This new distance, for example, is consistent with an interpretation of the spectrum of Goss et al. (1972) which probably shows absorption out to at least −40 km s^{-1} and a near kinematic distance lower limit at ≥3 kpc. A distance of ∼3.7 kpc is also in reasonable agreement with the estimate of ∼4.6 kpc suggested by Weiler & Panagia (1980) based on a less accurate set of SNR properties. If we take our new *ROSAT* derived age of $\sim 1.0 \times 10^4$ yr and assume the radio plerion and shell are cospatial and of similar age, the evolutionary relationship derived for plerions by Weiler & Panagia would place G326.3−1.8 at $D \simeq 3.2$ kpc, again consistent with our distance estimate for the shell.

We note that if the derived X-ray temperature gives only a lower limit to the actual SN shock front velocity, as has been suggested before (Aschenbach et al. 1991), the derived X-ray luminosity is an upper limit. An additional possibility which could lead to an overestimate of the X-ray luminosity for this object is the presence of an underlying X-ray plerionic component whose contributed flux we have attributed to the shell. When we performed spectral fits to the X-ray photons from only the expected plerionic region of the SNR (using the radio contours of Milne et al. 1989 to delineate this region, see Fig. 2) we found that emission from this region was well described by a thermal spectrum with $kT \simeq 0.52$ keV ($\chi 2 \simeq 17.7$ for 30 degrees of freedom). However, up to 40% of the observed X-ray flux from this plerionic region could have come from a power-law nonthermal component which we would have been unable to distinguish from the thermal shell emission.[1] In fact, a steep ($\alpha \simeq -4$) power-law, nonthermal component could have a luminosity which exceeds the luminosity of the entire thermal shell component ($\leq 4 \times 10^{36}$ ergs s^{-1}) with this softer plerionic nonthermal X-ray emission almost completely attenuated by the high value of $N_{\rm H}$ toward this source. If a nonthermal component of the spectrum is flatter ($\alpha \approx -0.5$), then the plerionic nonthermal X-ray luminosity constraint is significantly lower ($\leq 4 \times 10^{33}$ ergs s^{-1}). Our best conclusion, however, is that we have *not* detected significant nonthermal X-ray emission from the central plerion in G326.3−1.8 (see also § 4).

7. CONCLUSIONS

We have measured the X-ray emission from the radio-defined composite SNR G326.3−1.8 using the *ROSAT* PSPC. The detected count rates are compatible with earlier measurements made with *Einstein*. The observed X-ray emission coincides closely with the shell-like component of the radio emission and appears to be purely thermal. At our sensitivity no plerionic nonthermal X-ray emission has been detected. The emission is best fitted by a single thermal spectrum (with lines) with $kT = 0.56$ keV and an interstellar hydrogen column density $N_{\rm H} \doteq 8.9 \times 10^{21}$ cm^{-2}. This $N_{\rm H}$ is consistent with rough estimates scaled from optical extinction measurements. The inferred unabsorbed X-ray energy flux, over the range 0.1–2.4 keV, is $F_{x0} \simeq 3.9 \times 10^{-10}$ ergs cm^{-2} s^{-1}. From an assumed initial explosion energy $\epsilon_0 = 10^{51}$ ergs, the standard Sedov analysis indicates the SNR is $\sim 1.0 \times 10^4$ yr old, ∼20 pc in radius, at a distance of ∼3.7 kpc, exploded into an ambient interstellar medium density of ∼0.1 cm^{-3}, and has an X-ray

[1] We obtained this limit by determining the nonthermal power-law flux (with $-0.5 \leq \alpha \leq -4.0$) which, when added to the thermal component, still provides a fit to the data which is consistent with the pure thermal spectrum at the 95% confidence level using an *F*-test. For reference, the plerionic Crab Nebula SNR has $\alpha \simeq -2$ and plerions are known with both steeper and flatter X-ray spectra.

luminosity within the *ROSAT* energy band of $\sim 6.1 \times 10^{35}$ ergs s^{-1}. The calculated swept-up mass of $\sim 120\ M_\odot$ indicates that the SNR is well into the adiabatic phase as is assumed in the Sedov analysis.

Our analysis has led us to an improved estimate of the distance to G326.3−1.8 which is significantly beyond the only firmly established lower distance limit of 1.5 kpc. This new, independent distance estimate greatly strengthens and improves upon previous distance estimates of ∼3–5 kpc based on much weaker arguments. Our distance estimate is not strongly dependent on the only major assumption, that of an initial explosion energy $\epsilon_0 = 10^{51}$ ergs.

The ability to obtain accurate SNR distance estimates from X-ray data with a minimum of assumptions is indeed a powerful tool. Other distance estimates to large, shell-type SNRs are notoriously inaccurate and their poor quality greatly hampers studies of the sizes, energetics, evolution, and estimates of the physical properties of such objects (Green 1984). Thus, we can expect that similar X-ray observations of extended SNRs in the recently completed *ROSAT* all-sky survey hold the prospect of significantly improving the distance and therefore physical property estimates of many Galactic shell-type SNRs.

Finally, we note that the deeper X-ray observations of G326.3−1.8 are needed to set more stringent limits on any underlying nonthermal, plerionic component of the X-ray emission which the present observations have been unable to detect, but which are certainly suggested by the remnant's classic composite radio morphology.

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